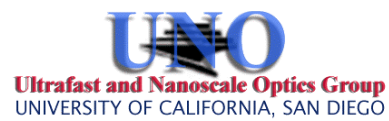
# Nanophotonics for On-Chip Integration of WDM Systems

DARPA WDM Workshop
April 18–19, 2000




Shaya Fainman
University of California, San Diego

# Report Documentation Page

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15. SUBJECT TERMS

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# Motivation

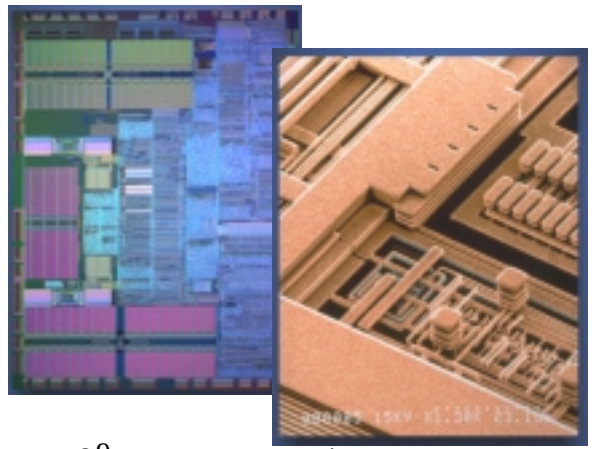
Microprocessors

IBM Mark I (1944)

~1000 instructions/sec

Si technology

PowerPC 750™ Chip (1999)



~$10^9$ instructions/sec

Optical Networks

Monterey 20000 Series Wavelength Router (1999)

256x256 OC-48 (2.5 Gb/sec)

?

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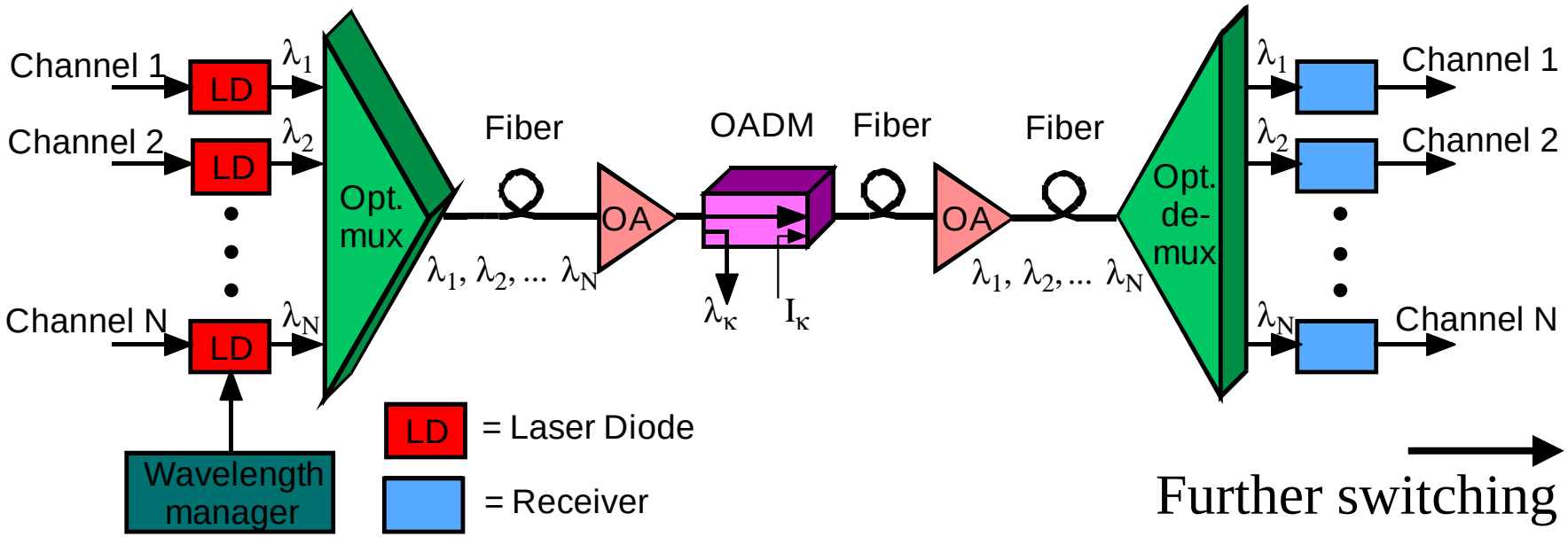
# Typical DWDM Point-to-Point Link with Add/Drop Capability

Even simple functionality requires complex hardware realization




Challenges:

- Integration
- Manufacturability
- Size
- Weight
- Cost

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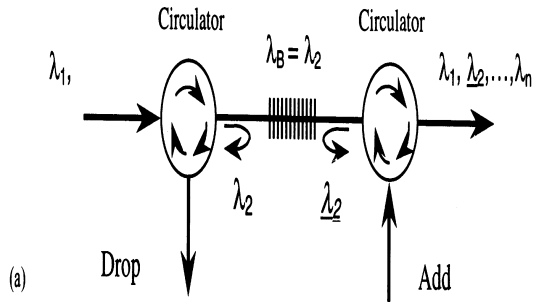
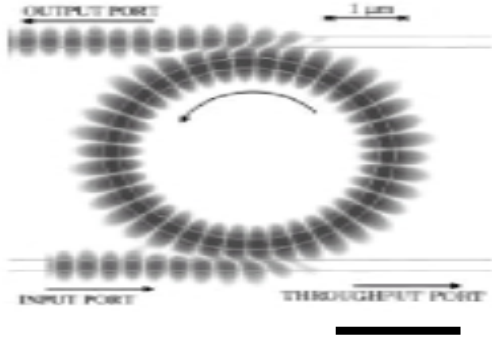
# Add/Drop Filter

## Fiber grating/free space

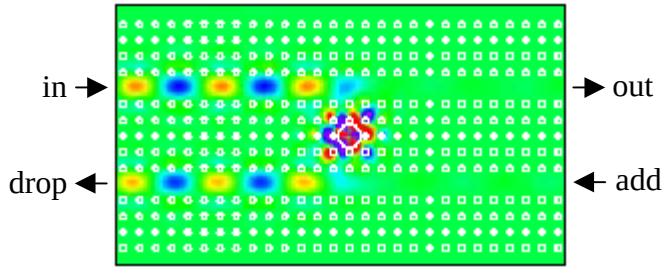



## Waveguide[2,3]

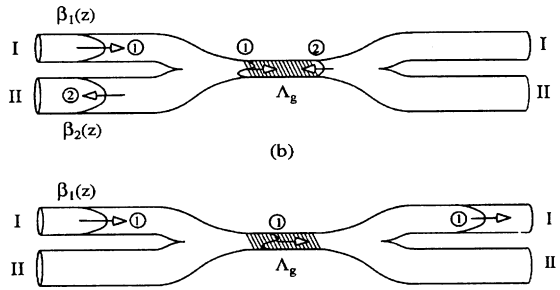


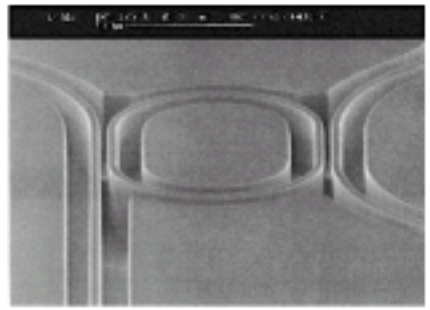

5 μm

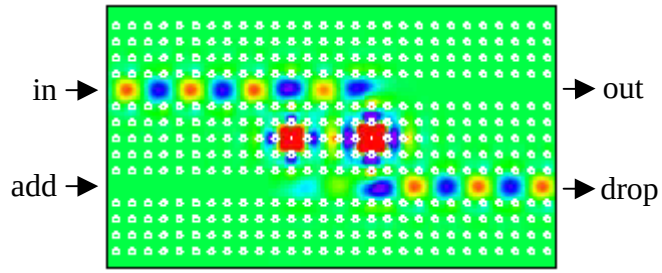
## Photonic crystal[4]




## All fiber[1]






1. A. S. Kewitsch, *et al.*,, "All-fiber zero-insertion-loss add-drop filter for wavelength-division multiplexing," Opt. Lett. **23,** 106–108 (1998).
2. B. E. Little, *et al.*, "Ultra-compact Si-$SiO_2$ microring resonator optical channel dropping filters," IEEE Photonics Technology Letters **10,** 549–551 (1998).
3. M. K. Chin, *et al.*, "GaAs microcavity channel-dropping filter based on a race-track resonator," IEEE Photonics Technology Letters **11,** 1620–1622 (1999).
4. Shanhui Fan, *et al.*, "Channel drop tunneling through localized states," Phys. Rev. Lett. **80,** 960–963 (1998).

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# Nanotechnology for Scalability and System Integration

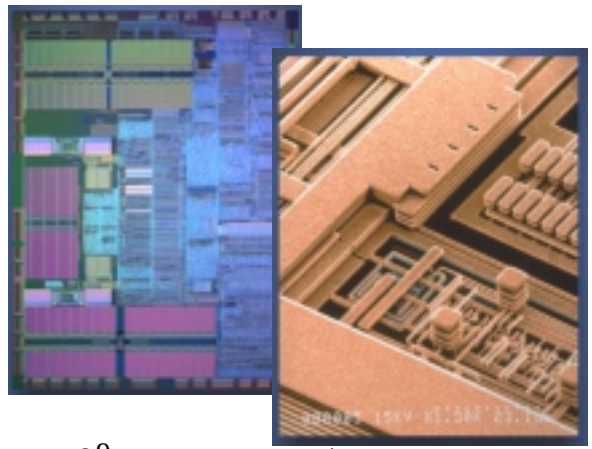
## Microprocessors

IBM Mark I (1944)

~1000 instructions/sec

Si technology

PowerPC 750™ Chip (1999)



~$10^9$ instructions/sec

## Optical Networks

Monterey 20000 Series Wavelength Router (1999)

256x256 OC-48 (2.5 Gb/sec)

Nano-technology?

Next-Generation Photonic Chips

- Higher performance
- Greater functionality
- Better reliability
- Improved manufacturability
- Smaller size
- Lower cost

# Artificial Dielectric Optical Nanostructures: Materials and Devices

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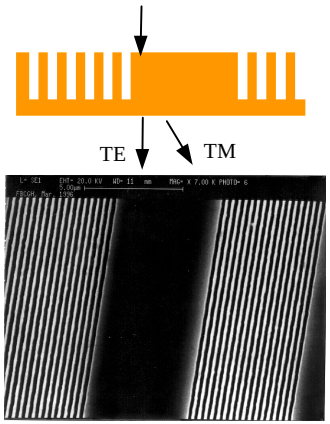
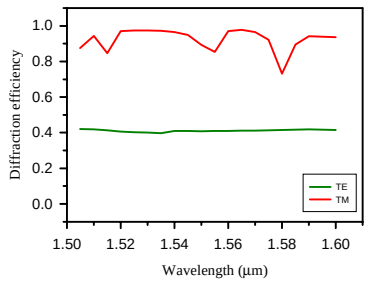
## Form Birefringent Computer Generated Hologram :

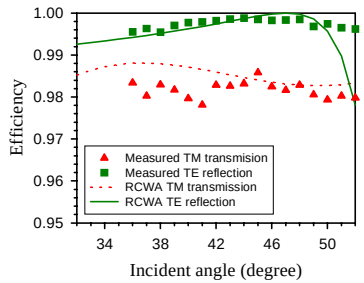
Multi-functionality and arbitrary phase profile

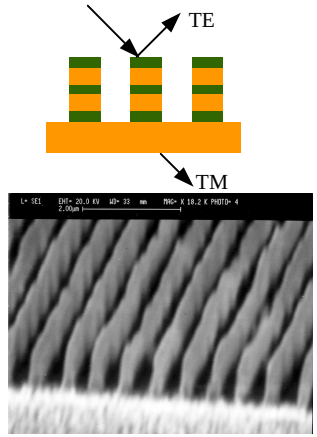


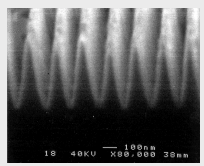

## Anisotropic Spectral Reflectivity Polarization Optics :

Large spectral and angular bandwidth, compact size, and normal incident operation



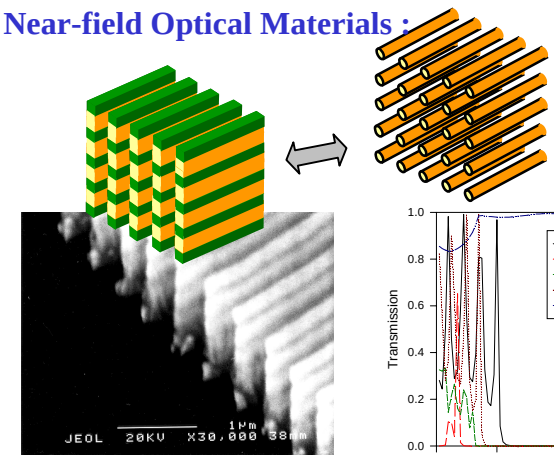




## Near-field interactions modify bulk material properties

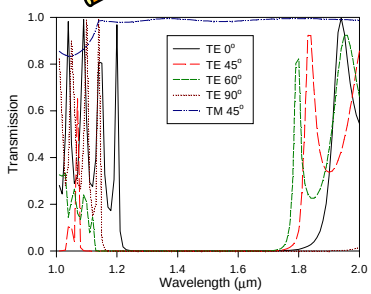


Experimental example* :
Material : GaAs
Incident wavelength = 920 nm
Grating period = 200 nm
Grating depth = 490 nm
Phase difference $\Delta\phi = 162.5^{o}$
$\Rightarrow \Delta n/n = 0.47$

## Near-field Optical Materials :

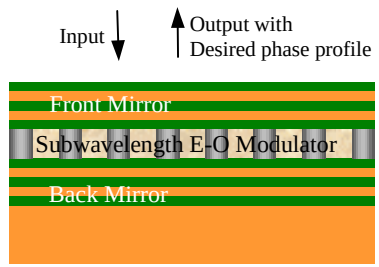


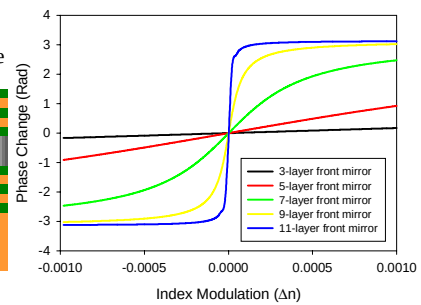

3-material photonic crystal




## Near Field Programmable Diffractive Optical Element :

Low voltage, compact size and programmability




fabricated in collaboration with Prof. Axel Scherer, CalTech

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# Near-field Nanophotonics: Methodology

## Idea:
Polarizing mirror

TM

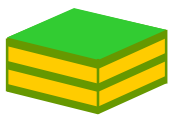
?

TE

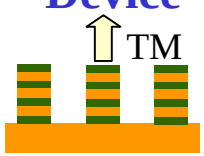
## Design


Form birefringence

+



Multilayer resonance

## Device


TM

TE

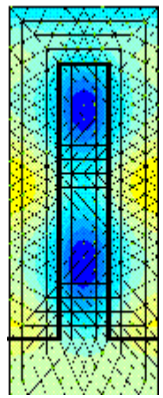
## Modeling Tools

### Fast-time-response
Finite-element Time-Domain

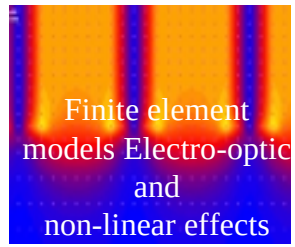
and

Finite-difference Time-Domain

model near field interaction in time domain

### Non-periodic


Finite element directly models near field interaction

### Periodic
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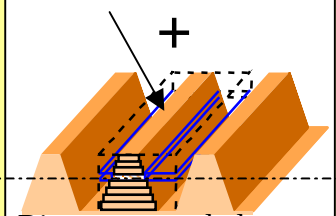
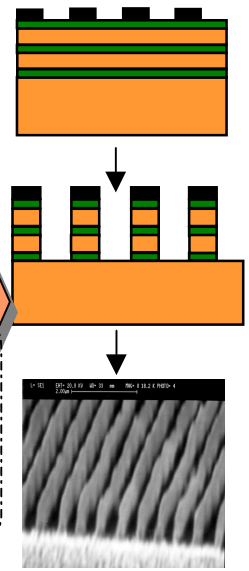
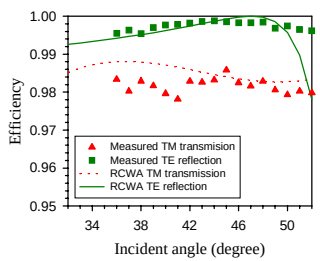


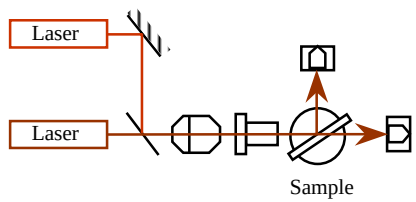
Rigorous coupled-wave analysis models near field interaction

## Fabrication




Subwavelength multilayer binary grating

## Characterization


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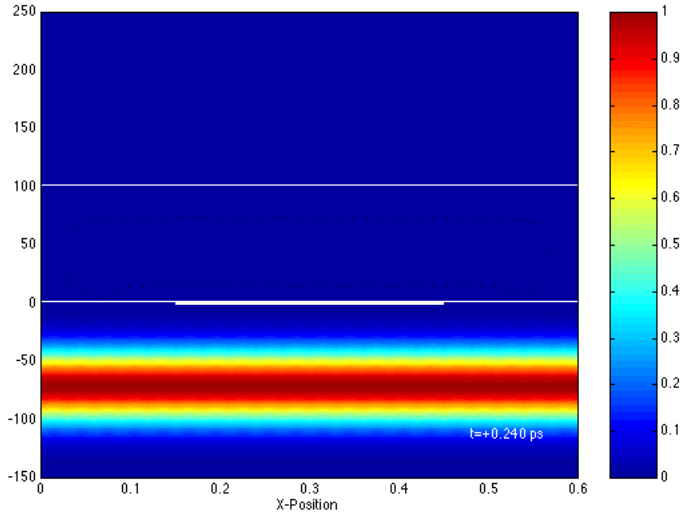
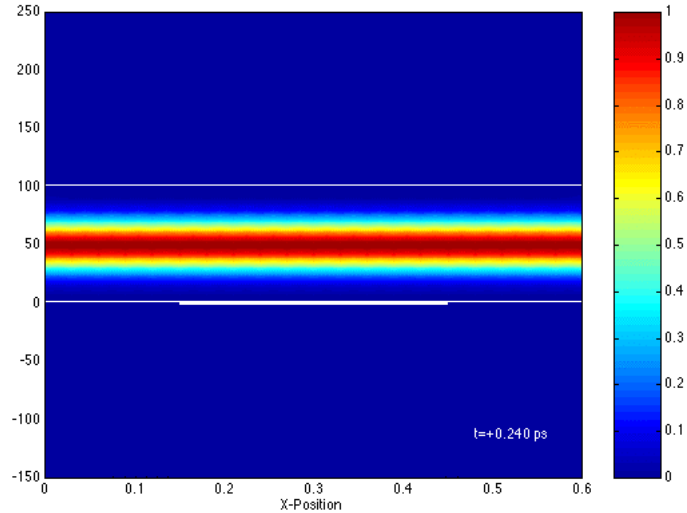
# Visualization of Modeling Results

TE Polarization

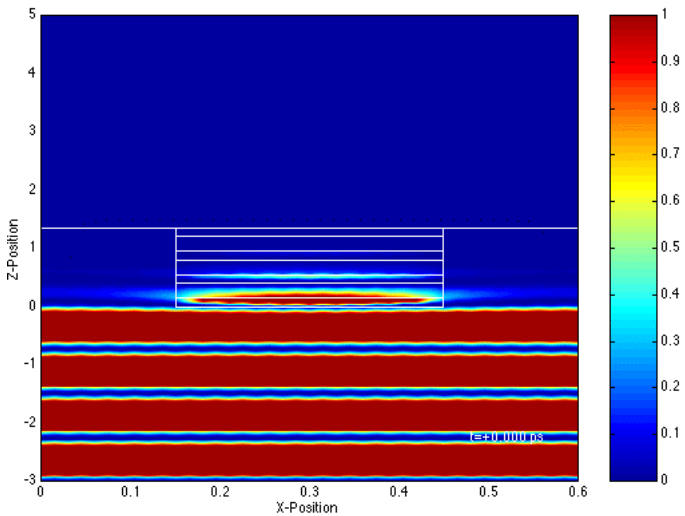
TM Polarization

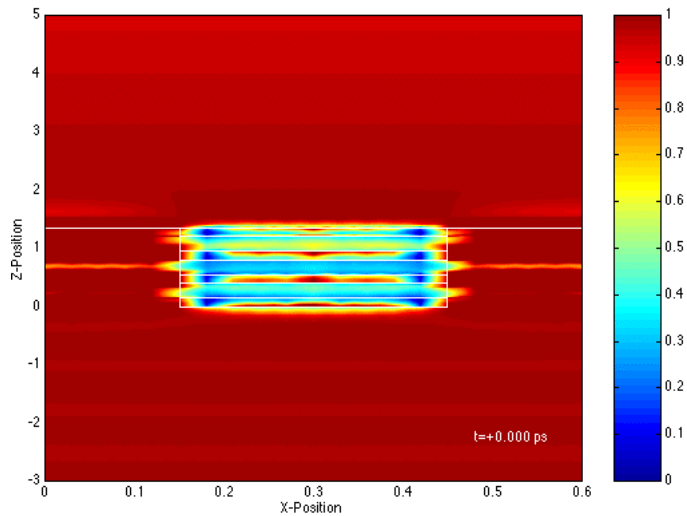
Wide view




Zoom view



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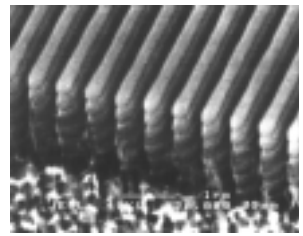
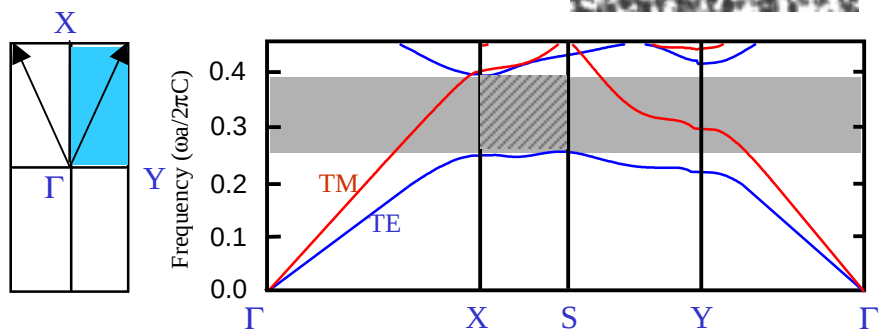
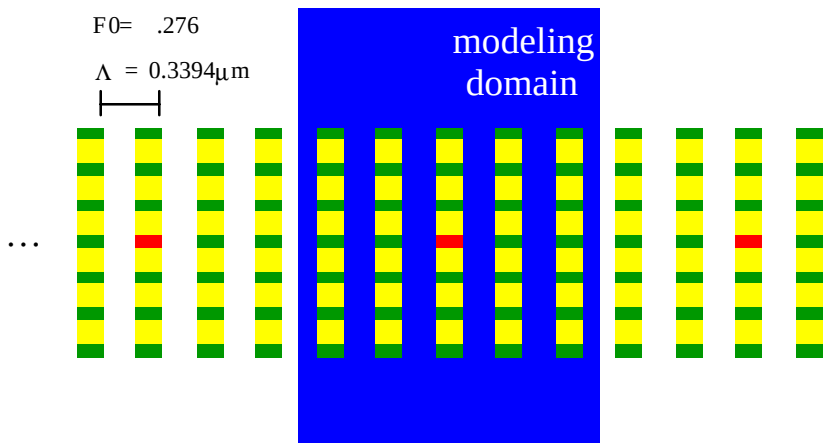
# 2-D Photonic Crystals using Artifical Dielectric Nanostructures

Implement 2-D PC using multilayer AD:



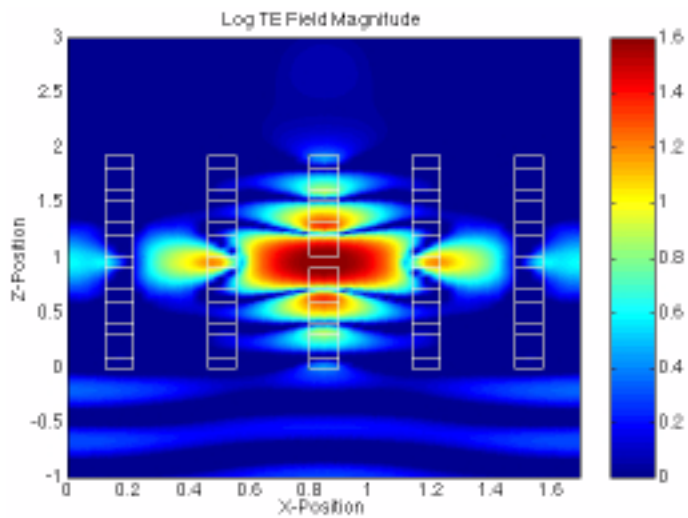



Defects in PC structure:




(monochromatic illumination)

λ = 0.907μm



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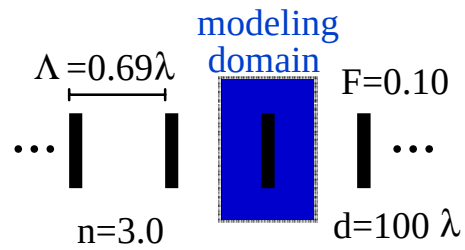
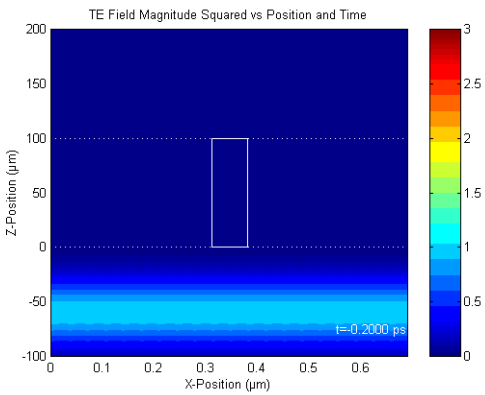
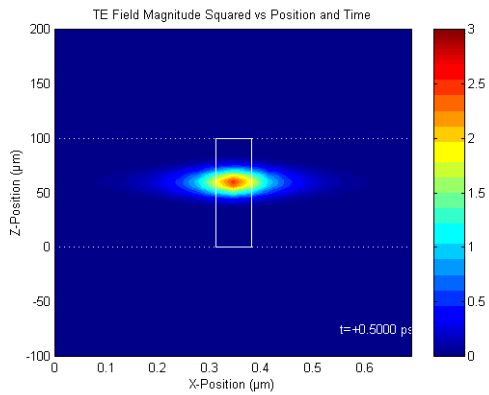
# Transverse Field Localization for Optical Nonlinearity Enhancement

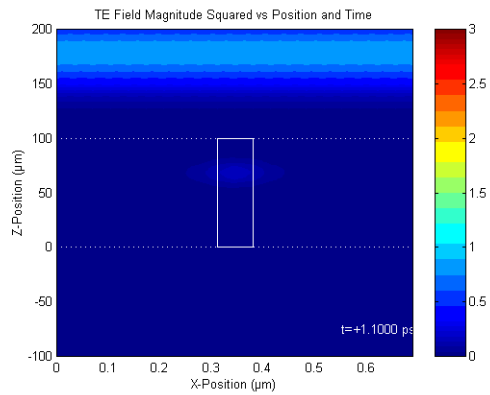
## Enhancement of nonlinear processes:

- temporal field localization (ultrashort pulse)
- transverse spatial field localization
- large nonlinear coefficients are typically found in high refractive index materials




## Approach:

- Array of coupled waveguides with single allowed mode result in transverse field localization in high index region
- Peak intensity is ~10 times that of bulk material

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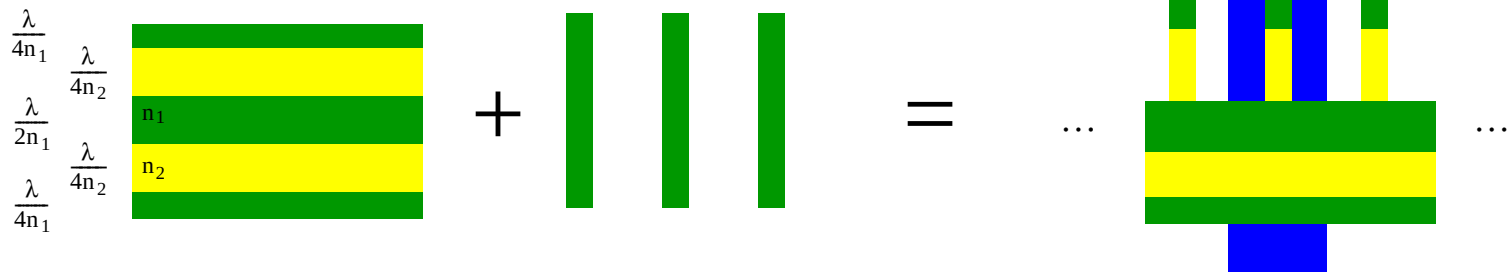
# Multifunctional Artificial Dielectric Nanostructure Device

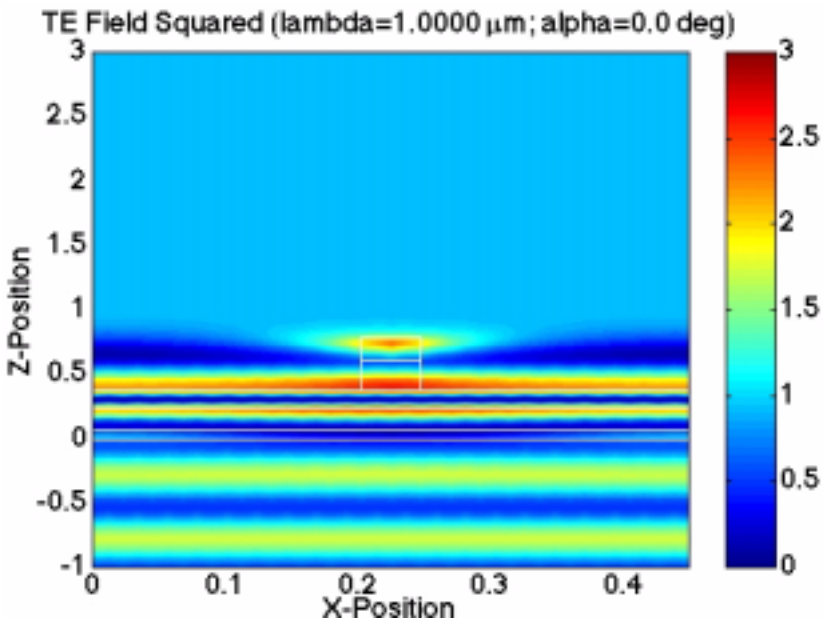
Multilayer resonant cavity filter

AD transverse field localization structure

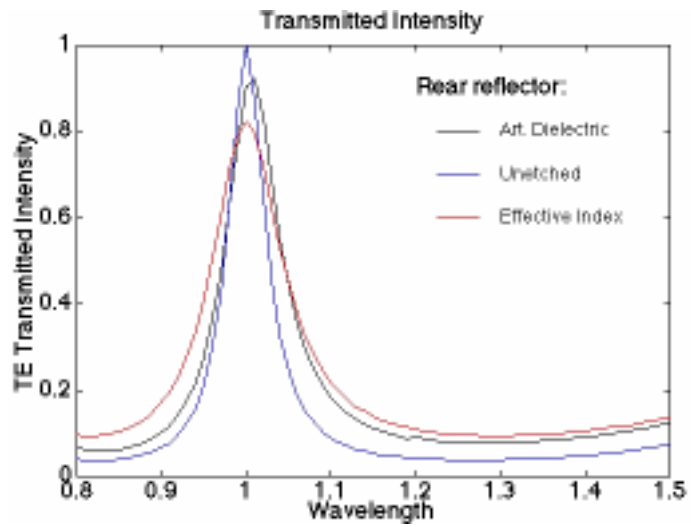
modeling domain




## Transverse field localization




## Transmitted Intensity



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# Artificial Dielectric Nanostructures

- Compatible with VLSI Technology

  materials and fabrication techniques

- Material Design Flexibility

  choice of materials; large, adjustable birefringence, dispersion

- Ease of Integration and Packaging

- Device Multifunctionality

  antireflection, phase retardation, polarization, color, programmable, enhanced nonlinearity

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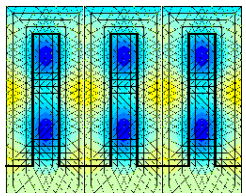
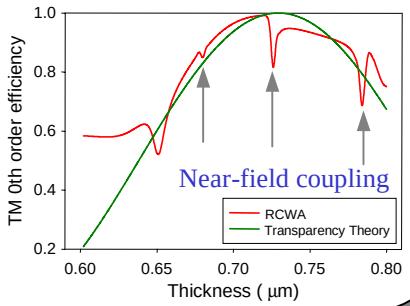
# Nano-optics for Photonic Integrated Chips

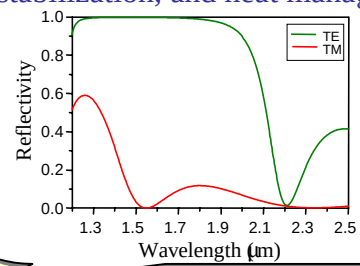
Near-field coupling between pixels in Form-birefringent CGH (FBCGH)

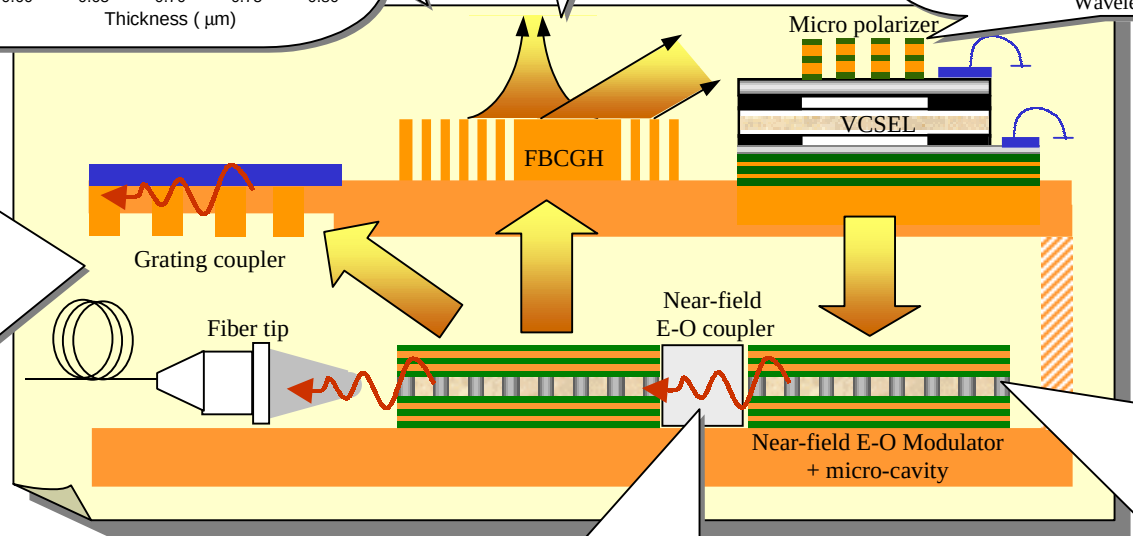




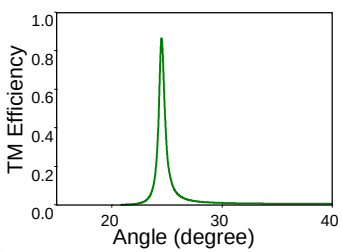

FBCGH possesses dual-functionality such as focusing and beam steering

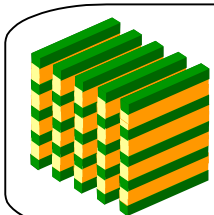
VCSEL + Near-field polarizer : Efficient polarization control,mode stabilization, and heat management



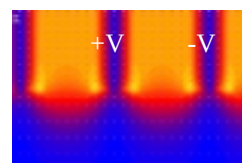




Information I/O through surface wave, guided wave,and optical fiber from near-field edge and surface coupling



Composite nonlinear, E-O, and artificial dielectric materials control and enhance near-field coupling




Near-field E-O modulator controls optical properties and near-field micro-cavity enhances the effect

Ultrafast and Nanoscale Optics Group
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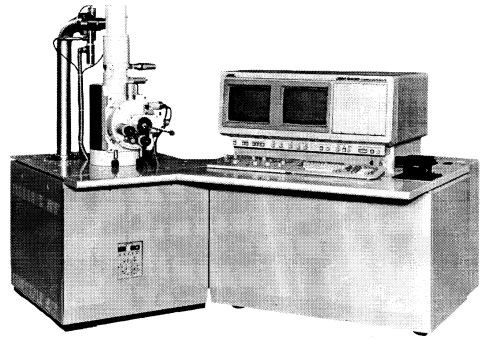
# Enhancement of Fabrication Facilities at UCSD

- Scanning Electron Microscope (SEM) for patterning and characterization



- Chemically-Assisted Ion Beam Etching

- Femtosecond Pulsed Laser Ablation

- DekTak Surface Profilometer

- Other UCSD fabrication facilities:
  - Electron Beam Lithography
  - Reactive Ion Etching